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THE GEOLOGY OF THE KILLDEER MOUNTAINS, NORTH DAKOTA

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The physiography of the Killdeer Mountains illustrates a case of rejuvenation without uplift. The drainage was rejuvenated by the deflection of the Little Missouri River due to the approach of an ice sheet. The deflection, which brought the Little Missouri River much nearer the mountains than it was before, produced a great increase in the gradient of the mountain streams.

A study of the rocks extends the known distribution of Oligocene formations in the Northwest. Much of the rock is limestone, and the formations appear to have been made by wind, river, and lake actions.

LOCATION AND DESCRIPTION

The Killdeer Mountains are in the western part of North Dakota, about halfway between Manitoba and South Dakota, and 50 miles east of the Montana line. They are part of the watershed between the Missouri and Little Missouri rivers, the watershed extending 250 miles southward to the Black Hills. The mountains consist of two mesas, called North Mountain and South Mountain, which are surrounded by cliffs which in some places are more than 100 feet high. The mountains cover an area of about 10 square miles, but they are so deeply cut into by streams that the plateau tops are less than 2½ square miles in area, and the periphery of the plateaus is about 30 miles. Most of the mountain area consists of slopes covered with talus and landslides, deep, wide valleys, and foothills characterized by decapitated slopes. Here and there steep-sided peaks rise from the plateaus, the highest being about 3,200 feet above sea-level, and about 150 feet above the plateaus. The mesa tops, which are upheld by a series of interstratified sandstone and limestone layers, are about 500 feet higher than the plains.

PHYSIOGRAPHY

Character and growth of the valleys.—The areal distribution of valleys in the Killdeer Mountains is relatively large. The main valleys are wide-mouthed, steep-sided, and nearly flat-bottomed. Numerous short, steep-sided gulches cut into the level upland. The slopes of the main valley floors are gradual because they are in uniformly soft clay and sand formations; but the heads and sides of the valleys are steep because they are bounded by the resistant interbedded limestone and sandstone in the upper part of the plateaus. The gulches and valley heads are still in infancy, whereas the lower valleys are farther along in their work of lowering the valley floors to the level of the plain. The valley floors are strewn with masses of resistant rock from the upper slopes. In some places the beds of the upper slopes have slipped down from their original position in such a way that they retain their horizontal position, although about 100 feet below the level in which they were in place. In some places streams have cut their way in behind the slump, thus increasing the slump by continually undercutting the already sliding cliff face. In some cases the slumps were started by the formation of caves. Several of these caves have the position of fissures, but their size and their irregular shape and the high lime content of the rock show that they were enlarged, at least, by solution. Nearly parallel to the south-facing cliff of South Mountain, near Oakdale, there is a cave opening known as Medicine Hole, which gives access to a crack at least 90 feet deep and a score or more feet long. This opening cuts through the limestone formation which caps that part of the mesa, and the bottom of the aperture is in the weak sand formation. Less than 100 feet south of the fissure is the cliff face of the upper hard ledge. As soon as this ledge is undermined a little more the separated mass will slump.

Spurs.—The advance of the valleys has left little but the spurs of what was once a much larger mountain. The spurs are long, skeletal, and straggling. Perhaps the most striking spur is the southeastern end of the South Mountain, just above Oakdale, but the southwestern end of the mountain is also notable (Fig. 1). It is almost a semicircle, half a mile in periphery, with precipitous inner walls. Below the cliffs lie benches and hollows due to landslips. The map shows that almost nothing of the mountains remains but spurs. If the contour intervals were smaller they would show that the slopes are benched on account of the varying hardness of the rock layers. There are three main benches, which are caused by hard layers referred to in the rock section as the lower, middle, and upper hard ledges, respectively. All the benches show as outcrops in the picture of Indian Knob.

Work of the wind.—At the base of thick resistant layers the wind has undercut the cliff as much as six feet. Undermining of the resistant layers causes the overhanging mass to be held in place by the shearing strength of the rock. If there were caves along the zone of stress, rupture would be likely to follow the plane of weakness. The layers of interstratified sand and limestone show the wind's work. The wind has scooped out the sandstone for eight or nine inches, leaving layers of the limestone projecting to this extent. In a less arid and less windy climate these conditions might be reversed.

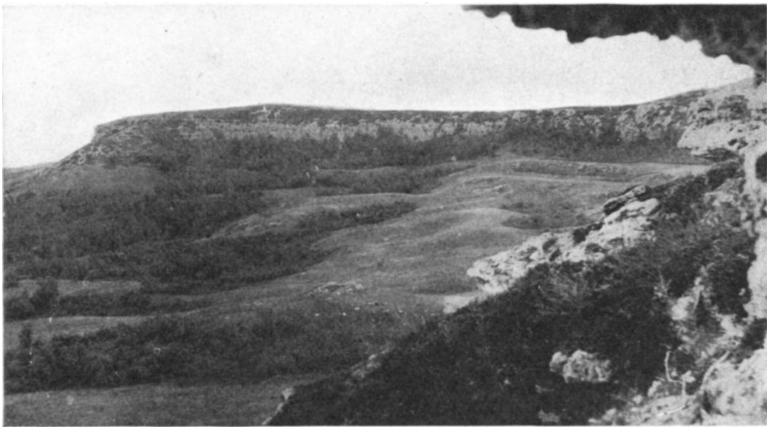

FIG. 1.—Southwest spur of South Mountain. It is almost a semicircle, half a mile in periphery, with precipitous inner walls, and landslide topography below.

Work of running water.—Charlie Bob Creek on the northwest, and Jim Creek on the northeast, both tributaries of the Little Missouri, are the chief agents of erosion. The tributaries of the Missouri River, particularly Knife River and its tributary, Spring

Creek, drain the mountains to the south and southeast (Fig. 2). From a distance the mountains appear to slope toward the north and northwest in long, smooth plains. Closer inspection, however,

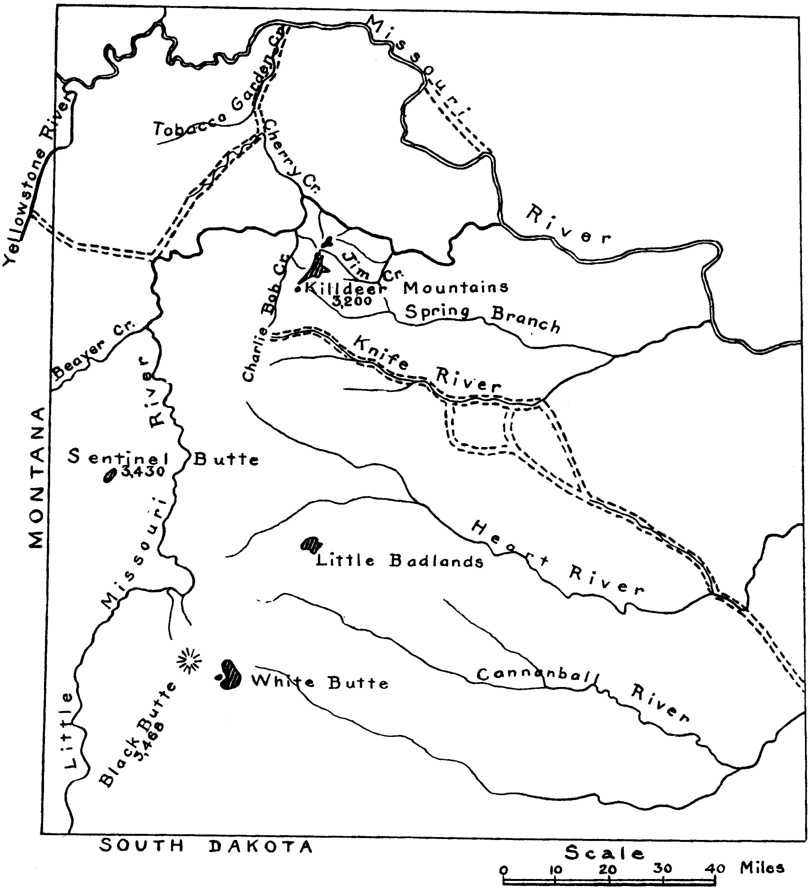

FIG. 2.—Map showing the distribution of the White River formation (shaded) in North Dakota. Abandoned Pleistocene channels are indicated by dashes. (After Leonard.)

shows that these slopes are fragmentary, and that many are decapitated by the tributaries of the Little Missouri River. These creeks have extended their heads westward through the gap between the mesas, so that in some places parts of two drainage systems may be seen: west of the gap uplands sloping to the west and streams flowing to the east, and east of the gap eastward flowing streams and remnants of an eastward sloping upland. The streams flowing northward likewise have cut into these long slopes, but since the heads of the streams have been working toward the south the action has been less effective, for direction of slope in this region makes a great difference in the rate of erosion. On steep, south-facing slopes in western North Dakota grass scarcely starts before the intensity of the sunshine and the shallowness of soil cause it to wither. On north-facing slopes the difference is remarkable, the lesser heat of the sun permitting a luxuriant growth of grass and several varieties of trees. Trees grow on the northward facing slopes to the top of the divides, but on the mountain top and on the southern slopes, outside of sheltered valleys, there are no trees. Indian Knob (Fig. 3), a conical hill on the southern border of the mountains, illustrates the effect of the sun. The south side is bare and precipitous; the north slope is clothed with brush to the very top. With little or no vegetation to hold the soil on the south

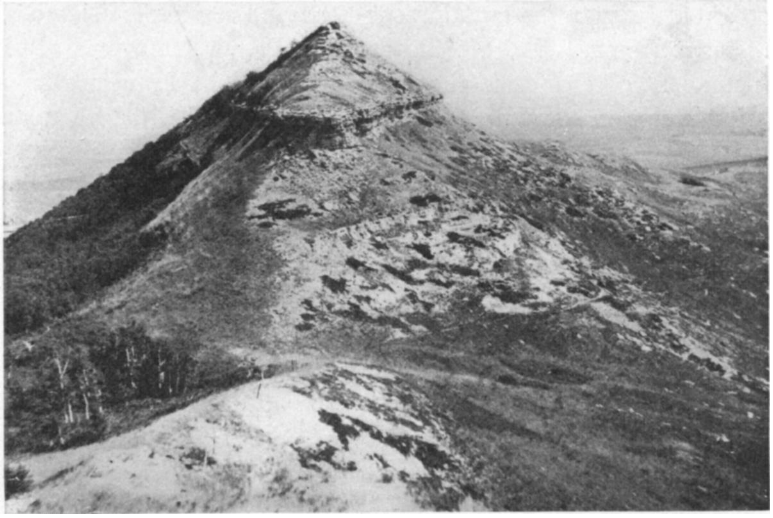

FIG. 3.—Indian Knob. This picture illustrates the withering effect of the sun's strength on the south slopes; it shows also the three hard ledges.

slopes erosion is much more rapid than it is on the north. Thus it is that streams which work their heads toward the north erode more rapidly than those which flow northward.

Rejuvenation of the drainage.—The north and northwest drainage down the upland slopes interosculates with the heads of the eastward flowing tributaries of Jim Creek, which have worked their way round North Mountain both to the north and to the south. They have cut off the heads of the upland slopes, leaving them separated from the mountain tops, stranded remnants of an older drainage system. This is indicated in Fig. 4. At present the chief agent of erosion is the Little Missouri River, whose tributaries have a maximum fall of 1,200 feet in 6 miles. The upland slopes show that there were once streams with a gradient much less steep. Previous to some pre-Wisconsin ice invasion, probably Kansan,[1] the Little Missouri River entered the Missouri through the valley of Tobacco Garden Creek[2] (Fig. 2). The ice sheet ponded the waters of the Little Missouri, Yellowstone, and Missouri rivers, and caused them to overflow to the southeast. After the retreat of the ice sheet the Little Missouri River did not return to its old course, but flowed eastward, north of the Killdeer Mountains, across the divide between its old course and the Missouri. This change rejuvenated the drainage of the Killdeer Mountains. The present surface of the valley now occupied by upper Cherry Creek and Tobacco Garden Creek is about 150 feet above the present level of the Little Missouri River channel, and that valley is 30 miles farther away from the mountains than the Little Missouri. Thus, before the glacial period, the Killdeer Mountains were not being eroded so rapidly as now, because the gradient of their drainage system to the northwest was only about 1,050 feet in 36 miles in place of 1,200 feet in 6 miles, 29 feet per mile in place of the present 200 feet per mile. The captured streams and numerous decapitated slopes about the Killdeer Mountains resulted from the Little Missouri River being turned by the glacial invasion from its northward course along Tobacco Garden Creek to its present eastward course 6 miles north of the Killdeer Mountains.

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[1] A. G. Leonard, *Quar. Jour. Univ. North Dakota*, VII (1917), 233.

[2] Frank A. Wilder, *Geol. Surv. North Dakota, 3d Bien. Rpt.* (1904), p. 119. Also *U. S. Geol. Surv. Water Supply and Irrigation Paper 117* (1905), p. 43. A. G. Leonard, "Pleistocene Drainage Changes in Western North Dakota," *Bull. Geol. Soc. America*, XXVII (1916), 302.

Stream piracy.—Formerly the divide between the Missouri and the Little Missouri rivers followed the long axis of the Killdeer

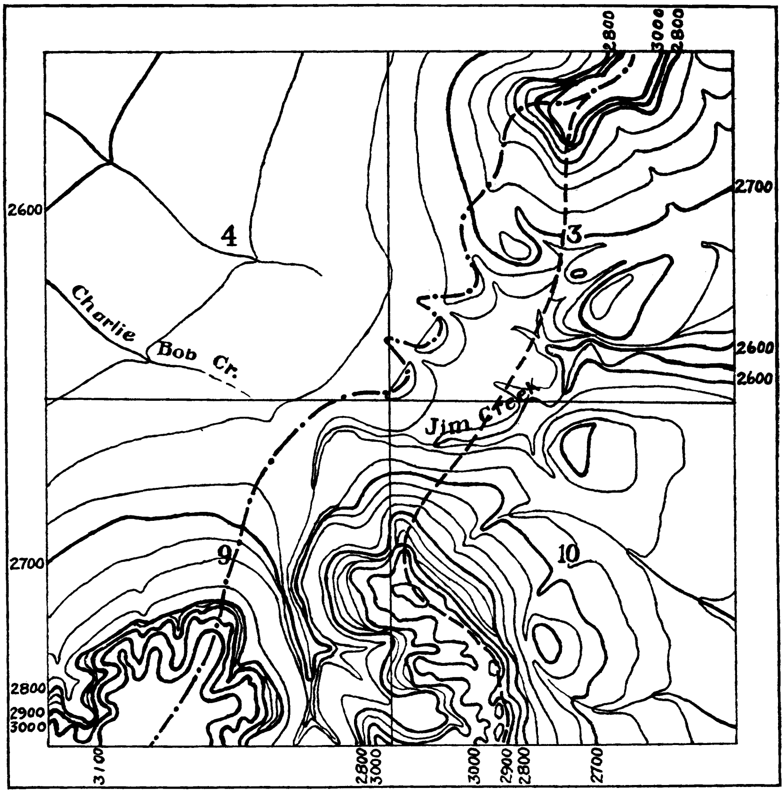

FIG. 4.—A representation of the change in a divide due to rejuvenation. The line of dashes denotes the position of the old divide between the Missouri and Little Missouri rivers. The dots and dashes indicate the present divide between two tributaries of the Little Missouri River. Note capture of the head of Charlie Bob Creek by Jim Creek, and the gorge cut in the old valley floor.

Mountains from north to south; now it passes along the south stretch of the South Mountain from west to east. The maps (Figs. 2 and 5) show what a considerable amount of stream capture attended the change. That part of the Little Missouri River

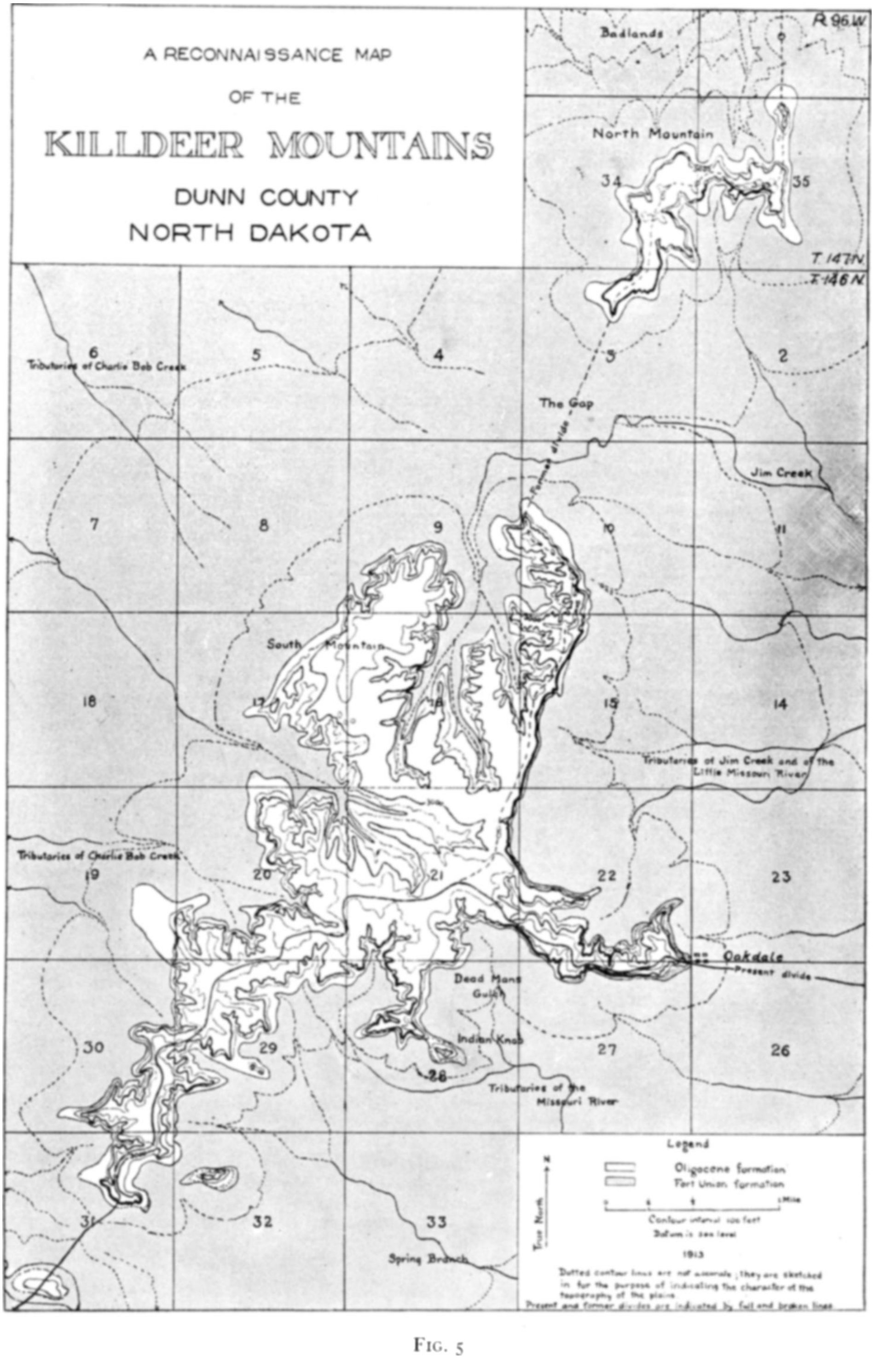
A RECONNAISSANCE MAP
OF THE
KILLDEER MOUNTAINS
DUNN COUNTY
NORTH DAKOTA
Badlands
R 96 W
North Mountain
34
35
T 147 N
T 146 N
6
5
4
3
2
Tributaries of Charlie Bob Creek
The Gap
Former divide
Jim Creek
7
8
9
10
11
South Mountain
18
17
16
15
14
Tributaries of Jim Creek and of the Little Missouri River
Tributaries of Charlie Bob Creek
19
20
21
22
23
Oakdale
Present divide
Dead Mans Gulch
Indian Knob
30
29
28
27
26
Tributaries of the Missouri River
31
32
33
Spring Branch
Legend
Oligocene formation
Fort Union formation
0
¼
½
1 Mile
Contour interval 100 feet
Datum is sea level
1913
True North
N
Dotted contour lines are not accurate; they are sketched in for the purpose of indicating the character of the topography of the plains.
Present and former divides are indicated by full and broken lines.

Fig. 5

which flows east follows probably the valley of a smaller tributary of the Missouri. Jim Creek, a tributary of the Little Missouri River, captured the head waters of Spring Creek, a tributary of the Missouri. Then the captured additions of Jim Creek pushed back into the gap between the two mountains until they cut off the head waters of Charlie Bob Creek, a fellow-tributary of the Little Missouri River. Fig. 4 shows the change in the divide between North and South mountains, and the change in the course of the creek which flows from the north valley of South Mountain.

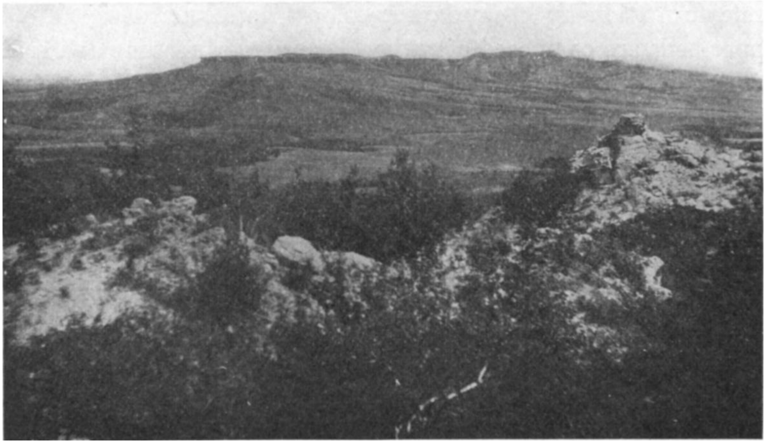

FIG. 6.—View from the northeast end of South Mountain, looking toward North Mountain. A vertical line through the center of the picture indicates the locus of the old divide. Compare with Fig. 4, and note the decapitated slopes.

Origin of the mountain features.—The character of the topography proves that the Killdeer Mountains are relict mountains greatly dissected by the ordinary agents of erosion. The rock strata are flat-lying and of unequal resistance. There are three strong layers which have given rise to the plateau tops and to two benches, one preserved only in the peaks, and one below the main table-land (Fig. 6). The decapitated slopes and the cases of stream piracy were caused by rejuvenation of the drainage due to a post-Kansan change in the course of the Little Missouri River.

STRATIGRAPHY

The geologic formations which compose the Killdeer Mountains are of Cenozoic age. The whole of Dunn County is underlain by the Fort Union formation of the Eocene system; the upper 400 feet of the strata forming the mountains is here referred to the White River formation of the Oligocene system.

Fort Union formation.—In the region of the Killdeer Mountains the lower strata belong to the upper part of the Fort Union formation. In general these beds differ from the lower members of the same formation by their darker color. As Leonard says, "The upper beds are composed of rather dark gray sandstone and shale, with many brown, ferruginous, sandy nodules and concretions."[1] The beds are of possible value by reason of lignite and beds of high-grade, white, plastic clay.[2] Other characteristics of these members of the Fort Union formation are carbonaceous shales, nodular ferruginous concretions, and many selenite crystals in beds of clay and shale.

White River formation.—In contrast to the dark color of the upper Fort Union formation the southern exposures of the Killdeer Mountain sides are as white as chalk. Throughout the entire thickness of 400 feet of the upper strata there is scarcely a trace of carbonaceous material, especially no lignite. The clays are calcareous and low in plasticity. Unlike the firm-grained, compact fire clays of the Fort Union formation, the clays are crumbly in texture and so loosely packed that some are porous. Limonitic coloring and concretions, common in the Fort Union beds, are rare in the upper strata. The small amount of iron present is in the ferrous form, tinging the rocks pale green. Certain hard sandstones and some of the clays and coarse sands are dark green. There are several layers of limestone, whereas, save for a few thin beds, limestone has not been reported as a phase of the Fort Union formation in North Dakota.

The outcrops on the mountain sides are few and nowhere continuous from the bottom to the top. Fossils are either very rare or wanting in these deposits, none being found in spite of diligent search. Only three places were found where the contact between the Fort Union formation and the beds above is exposed. A discrepancy of 41 feet between the elevations of these places shows that the contact is uneven. Furthermore it is apparent that the Fort Union rocks were oxidized and eroded before the deposition of the basal unoxidized stratum of the overlying formation.

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[1] A. G. Leonard, *Geol. Surv. North Dakota, 5th Bien. Rpt.* (1908), p. 45.

[2] E. J. Babcock and C. H. Clapp, *Geol. Surv. North Dakota, 4th Bien. Rpt.* (1906), p. 132.

A generalized composite section of the younger formation, worked out from eight partial sections, is as follows:

WHITE RIVER FORMATION, KILDEER MOUNTAINS, NORTH DAKOTA

7. Pale-green, fine-grained, calcareous sandstone, interstratified with subordinate amounts of marl, hard layers of white limestone, and lenses of green, cherty sandstone. 97 feet.

6. Upper hard ledge, a layer of ash-gray, arenaceous limestone. In the southern part of the mountains there are green, cherty lenses and layers of quartzite within this calcareous member. 6 feet.

5. Chalklike, soft, arenaceous marl. 64 feet.

4. Middle hard ledge, upholding the main plateaus. Greenish-gray, white weathering, interstratified limestone and friable sandstone. Rootlike stringers of white calcium carbonate join the layers of limestone through the sandy layers. In the north part of the mountains the ledge is almost solid limestone; in the southern outcrops the rock is sandy, porous, and apparently made up of grains of limestone and silica. 30 feet.

3. Pale-green, friable, cross-bedded sandstone. In the southern outcrops it appears to be wind laid, but at the north end there are several layers of limestone with the sand. 30 feet.

2. Lower hard ledge, a layer of pale-green, fine-grained, calcareous sandstone, much like the middle hard ledge, but it is limestone near the north end of the mountains. 10 feet.

1. Green, crumbly, non-plastic clays, and green, fine and coarse, uncemented sands. At the southern end of the mountains there is a pebbly conglomerate layer one foot thick near the base of the member, and in a calcareous phase there are pebbles of limestone, quartz, and granite scattered sparsely throughout the rock. 170 feet.

Total thickness about 400 feet.

Most of the rocks are water laid, but part of member No. 3 is Eolian. The rocks are characteristically loosely cemented and very friable, but some of the sand is indurated to quartzite. The cement is chalcedonic and opaline quartz. Many pieces of opal were found; some are transparent and very pale blue, others are milky white, and a few are dark brown with white streaks resembling the grained appearance of silicified wood.

The limestone layers are all siliceous, the silica being in very fine grains. Some of the limestone is clearly clastic in character, the constituent grains being distinguishable by the naked eye. One specimen of limestone taken from the upper hard layer contains 47.7 per cent $CaCO_3$, but the sand content lowers the amount of $CaCO_3$ below this figure in most of the rock.

The clays are characteristically pale green or pink, loosely granular in texture, and but slightly plastic. When a piece of the green clay is dropped into water it falls into fragments. Within a minute after a small piece is put into water it has disintegrated into very small flakes which have the appearance of a green, flocculent precipitate. When made into stiff mud and used as a plaster the clay hardens on drying and serves the people of the district in place of lime. Although they call it "natural lime" and use it for many purposes, even in place of putty to fasten glass in window sash, as mortar, and as a wall wash, the rock contains less than 2 per cent lime.

Correlation with White River deposits.—These rocks are unconformable on the Fort Union formation. The only sedimentary beds which are known to lie on the Fort Union formation in North Dakota belong to the White River formation. These beds are White Butte, Little Badlands, and Sentinel Butte deposits, all of which are similar to the Killdeer beds. White Butte deposits near Sandcreek post-office, Billings County, were discovered by Cope in 1883. He wrote: "The beds, which are unmistakably of the White River formation, consist of greenish sandstone and sand beds of a combined thickness of about 100 feet. These rest on white calcareous clay rocks and marls of a total thickness of 100 feet. These probably belong to the White River epoch, but contain no fossils."[1] From the upper beds Cope collected several fossils of vertebrates, including species of Aceratherium and Oreodon. Leonard describes these beds as "conspicuous, snow white elevations."[2] Further he continues: "The White River group is here composed of white clays at the bottom, on which rests a coarse sandstone which in places is filled with large pebbles; this is overlain by about 100 feet of calcareous clays which in turn are overlain by more than 100 feet of fine-grained, greenish sandstone." From the calcareous clays he reports the finding of an Eporeodon major skull. Earl Douglass[3] reports Mesohippus, Aceratherium, Ictops, and Merycoidodon fossils from the beds at White Butte. The remains are fragmentary and scarce, but enough fossils have been found to place the beds without question in the White River formation.

In the same report Douglass reports Oligocene strata at the Little Badlands 26 miles northeast of White Butte and about 14 miles southwest of Dickinson. The section of the beds which he gives is similar to that of White Butte; there also he found enough fossils to identify the beds as of the White River formation.

The strata at the top of Sentinel Butte belong probably to the Oligocene series. They are composed of light-gray calcareous clay or marl, which contains toward the top beds of a nearly white, compact limestone. These beds contain fossil fishes which are not closely related to any previously described; therefore, by means of these, Plioplarchus whitei Cope, and Plioplarchus sexpinosus Cope, no correlation is possible.[4] Sentinel Butte is about 40 miles west of northwest of the Little Badlands and about the same distance north of northwest of White Butte (Fig. 1).

The Killdeer Mountains are about 50 miles northwest of Sentinel Butte and about 45 miles north of the Little Badlands. Sentinel Butte is part of the divide between the Little Missouri River and its tributary on the west, Beaver Creek; with one exception it is the highest point in the state, being 3,430 feet above sea-level. The other known remnants of the Oligocene formations lie near the top of the divide between the Little Missouri River and the eastward flowing tributaries of the Missouri. Starting at the Black Hills, South Dakota, and following the divide north one comes to the White River formation first in Slim Buttes, then 20 miles farther north in the Cave Hills[1] deposits, which are only about 40 miles south of the White River strata on White Butte.

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[1] E. D. Cope, *Proc. Amer. Phil. Soc.*, XXI (1883), 216-17.

[2] A. G. Leonard, *Geol. Surv. North Dakota, 5th Bien. Rpt.* (1908), p. 65.

[3] Earl Douglass, *Annals Carnegie Mus.*, V, Nos. 2 and 3 (1909), pp. 281 ff.

[4] C. A. White, *Amer. Jour. Sci., 3d Ser.*, XXV (1883), 411-16; A. G. Leonard, *Geol. Surv. North Dakota, 5th Bien. Rpt.* (1908), p. 64.

If one were to look for another remnant of the Oligocene beds to the north of the Black Hills he would continue logically in the direction of the known deposits, along the divide just outlined. If the Oligocene deposits once extended over the Killdeer district the elevation of these hills is such that they might well contain remnants of these deposits. The Killdeer Mountains are about 3,200 feet high and contain a thickness of almost 400 feet of Oligocene-like beds. The beds on Sentinel Butte at an elevation of 3,340 feet are only 40 feet thick. The thickness of the White Butte and Little Badlands deposits at lower elevations are about 320 and 200 feet respectively. A still greater thickness of Oligocene deposits at the Killdeer Mountains is explained by the general northeastward dip of the Fort Union strata north of Dickinson, North Dakota.

Because the deposits of the Killdeer Mountains are unconformable on the Fort Union formation, because they are similar in character to undoubted deposits of the White River formation less than 50 miles distant, and for physiographic reasons they are referred to the White River formation.

Origin of the White River deposits.—Professor Cope[2] wrote of the discovery of the White Butte deposits as "the locality of a new lake of the White River epoch." Todd[3] considers the White River beds of South Dakota to be lake deposits. Earl Douglass says:

> I have little doubt that the upper Tertiary deposits in North Dakota were also deposited in broad valleys of erosion. Much of the material of the deposits came from areas of granite and quartzite rock. In the region of the Black Hills are the only outcrops of these rocks for hundreds of miles; this, connected.

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[1] J. E. Todd, *Geol. Surv. South Dakota, Bull. No. 2*, p. 123.

[2] E. D. Cope, *op. cit.*, p. 216.

[3] J. E. Todd, *op. cit.*, p. 60.

> with the fact that a series of remains of Oligocene deposits have been observed to extend from Dickinson to the Black Hills, suggests the probability that a river formerly flowed from the Black Hills northeastward through this region. If this be true, there should be coarse sediments as the mountains are approached, which is probably the case. Another thing which tends to confirm the idea that these are river valley deposits is the fact that, scattered over the plains, there are buttes apparently as high as White Butte, but which are not capped by later Tertiary beds.[1]

However, the apparent anomalous deposition on White Butte is explained by Leonard in another way:

> The beds of the White River group are wanting on Black Butte, although occurring at a considerably lower level only three miles to the west. In White Butte they are, however, found resting directly upon the thick upper sandstone of the Fort Union, which outcrops at several points near the base of the western slope of the western ridge, and also at its northern end. This sandstone here dips strongly to the east, so that within a distance of three miles its dip carries it from the top of Black Butte to the bottom of the ridge on the opposite side of the valley, where it is over 200 feet lower.[2]

It is believed that the beds on Sentinel Butte are lake deposits, and that some at least of the beds on White Butte are river deposits, especially the pebbly conglomerates.

At the Killdeer Mountains the greater part of the deposit is distinctly lacustrine, but some of the layers are wind worked. At the southwestern corner, however, on the south side of South Pass in the SW. ¼ Sec. 31, there are various remnants that suggest a river inlet. On the south face of this isolated hill there is an outcrop of coarse, yellow sandstone which is interbedded irregularly with bright-red, hematitic sandstone. It shows interrupted deposition by cross-bedding and lenses. This coarse sandstone is about 15 feet thick, covered by finer, more loosely cemented, pale, yellow-gray sandstone. It is a small outcrop, extending about 200 feet and abruptly ceasing. Above the sandstone there are water-worn pebbles, as large as three inches in length, scattered over the surface. These were traced back into heavy limestone masses, which show pebbles widely scattered on weathered surfaces. In a few places there is a thin ledge of very coarse sandstone carrying small pebbles;

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[1] Earl Douglass, *op. cit.*, p. 288.

[2] A. G. Leonard, *Geol Surv. North Dakota, 5th Bien. Rpt.* (1908), pp. 65-66.

there is also a soft, sandy limestone of loose texture carrying gravel. Similar pebbles and residual masses of limestone were found out of place on the lower slopes of the south side of Indian Knob, but the pebbly limestone could not be traced back to the rock still in place. Also, on the south side of North Mountain a few scattered pebbles of the same general description were found, but again none could be found in place. The pebbles are of quartz and igneous rocks, with many limestone pebbles, some of which are pale green in color. It is conceivable that some of these pebbles were carried into the region where limestone and fine material were being deposited by cakes of ice or in the roots of floating trees. But at the southwest end of the mountains the abundance of the gravel leads to the supposition that at that place there may have been the debouchure of a river emptying into a lake. Furthermore the lower hard ledge does not continue distinctly in the southwest end of the mountains, whereas in the northern part it is almost solid limestone. From the fact that the limestone is more pure in the north end of the deposits it is argued that that end was farthest from the entrance of the river. Another item to support the supposition that the material was brought by rivers from the south is the fact that the gravels in White Butte are much coarser than any which have been found 100 miles farther north in the Killdeer Mountains. If it is argued that these deposits were laid down in small lakes connected by a single river, it should be remembered that gravel could not have been carried through one lake and on to deposition in the next. And as there is gravel in the deposit in South Dakota, again 50 miles farther north in White Butte, and again 100 miles farther north in the Killdeer Mountains, it must be supposed that the gravels were already distributed along the course of the river by some earlier and uninterrupted stream. This accords with Douglass' theory that the Oligocene deposits are in the channel of an earlier river.

The alternate hypothesis is that only the lower beds represent the work of a river, and that the upper beds, which are free of gravel deposits, were formed in a lake which overlapped the river deposits. The scattered outcrops of Oligocene deposits are explained better as the remnants of an almost eroded formation than as deposits of different lakes joined by a river or rivers, for the deposits are found only near the top of the divides. They were once probably continuous and widespread. Furthermore the major part of the Killdeer deposits are of fine materials derived from a basin rich in limestone. The fineness of the materials betokens long transportation and thorough sorting, for the gravels are found only in the lower strata and only near the southern part of the deposits. The limestone layers are mechanical rather than chemical or organic deposits. The stream supplying the Oligocene lake must have been rather swift to carry so much calcareous and siliceous mud, and it must have come, without passing through any settling ponds, directly from the limestone highlands in the south.

CONCLUSION

The Killdeer Mountains are relict mountains on the divide between the Little Missouri and the Missouri rivers. They are deeply dissected by the tributaries of the Little Missouri River. Erosion has been hastened by the rejuvenation of the drainage due to a change in the course of the Little Missouri River. The change was caused by the advance of a pre-Wisconsin ice sheet, probably Kansan. The change increased greatly the gradient of the streams flowing from the mountains and gave rise to many cases of stream piracy; hence there was rejuvenation without uplift.

The upper strata of the mountains are correlated with the White River formation. This extends considerably the known distribution of the Oligocene series. Study of the formation leads to the conclusion that some of the lower beds were deposited by a river and that most of the rocks were laid down in a lake. The lake was fed by a river flowing northward from the Black Hills and transporting large quantities of calcareous silt from South Dakota to western North Dakota.